Proposal for an AIAIM 2019 special session on "**Communication-aware control in cyber-physical systems**"

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***Abstract*—Cyber-physical systems (CPSs) consist of physical parts (e.g. real plants, actuators) and cyber parts (e.g. smart sensors, digital processors, softwares, transmitters) interacting through analog-to-digital/digital-to-analog converters and wireless communication networks. Due to cheap and efficient digital devices with fast sensing, big data processing and communication capabilities, CPSs possess flexibility in design, low cost of installation and ease of maintenance. In the past decade, CPSs have been utilized in many scenarios including industrial process, intelligent manufacturing, power generation, transportation and aerospace. Hence, CPSs are identified as one of the most promising topics for future research. Meanwhile, the cyber parts also expose CPSs to constraints induced by limited communication bandwidth, imperfect received data, transmission latency, and even malicious attacks launched by smart attackers. These factors raise challenging control problems in CPSs, which we are interested in. Although time delays, packet drops and quantized signals have been extensively studied, often they are not adequate to characterize true CPSs subject to diverse communication constraints. Thus, there are still many control problems open, in particular because of communication. In order to share the latest developments in this direction, we propose this special session in the China-Qatar International Workshop on Artificial Intelligence and Applications to Intelligent Manufacturing (AIAIM), Doha, Qatar, January 1-4, 2019, which will present recent advances in communication-aware control of CPSs and some applications.**

I. Motivations

Cyber-physical systems are the next generation of engineering systems, with applications spanning critical infrastructures, automotive systems, energy conservation, environmental monitoring and robotics. Often, there is not only one physical part or one cyber part in these applications. In general, a CPS involves multiple physical subsystems and cyber subsystems, and thus is a kind of extension of networked control systems as well as multi-agent networks which have been studied extensively in the past decade [1, 2]. One of their major features is the fact that data and commands are broadcast through communication networks, in particular wireless communication [3]. We want to stress that any digital media cannot carry the information exchanged among subsystems in a CPS precisely:

- Most sensors can only monitor and capture the information of interest, denoted as $x(t)$, intermittently. Then the sampled data $x(t_k)$ cannot be a complete copy of $x(t)$.
- The sampled data $x(t_k)$ needs to be quantized and then saved in memorizers in the form of '0' and '1'. Note that the saved data $x_q(t_k)$ losses more information compared with $x(t)$.
- The data $x_q(t_k)$ will be sent to other units one stack by one stack in a CPS, for example, the remote controller in a networked control system, or the neighboring agents in a multi-agent network. Both sampling and sending could delay the data. Besides, data dropout can also happen.
- By using the imperfect received data, the designed controller is supposed to produce desired control input commands, which will be sent to the actuator through communication networks and can be followed by the actuator to control the real plant. During this procedure, the above issues exist as well.
- Moreover, the use of communication networks makes it possible for malicious attackers to inject adverse data or remove part of the transmitted data. Unfortunately, we do not know how the attackers attack the communication network in advance.

Therefore, a competent controller for a CPS should be able to produce suitable control signals in the presence of imperfect information mainly due to communication. The so-called *communication-aware control* problems are what the control people have to confront, but also exactly what we are interested in. Of course, apart from these issues caused by digital computation and communication, CPSs are vulnerable to many other adverse factors, e.g. sensor and actuator failures.

In order to handle the above controller design problems, people have proposed an amount of methodologies and the results are fruitful. Although we have no a unified framework for control of CPSs, the existing control approaches can be sorted into two categories: *active control* and *reactive control*. Most well-known control approaches are in fact reactive control in the sense that the controller design closely follows particular assumptions on communication constraints. For example, delay times are usually upper bounded by a given positive constant which is involved in the design of a suitable controller. The obtained controllers are somehow quite conservative and may only work under the imposed assumptions.

In active control, people devote to designing controllers for CPSs using *as less communication as possible*. Sampled-data control is indeed a reactive control approach due to the sampling mechanisms of sensors and the fact that the sampling frequency cannot exceed the working frequency of the sensor. On the other hand, sampled-data control can be also viewed

as a kind of active control approach since we can minimize the allowable sampling frequency in order to reduce the use of the sampled-data.

Different from periodic sampled-data control, the event-triggered strategy was proposed to make sampling adaptively in terms of the control goal [4]. Under event-triggered control, the control task is executed after the occurrence of a well-designed event. In this way, the unnecessary waste of computation and communication resources can be mitigated. From the perspective of communication energy, time-triggered control works efficiently by taking into account the fluctuations of the wireless channel [5]. Furthermore, intermittent feedback control can greatly reduce the use of computation and communication resources but also the use of actuators, see Chapter 4 in [1].

We still lack the ability to design controllers for CPSs in a systematic and scalable way. In addition to communication issues, CPSs also pose problems at the intersections of many other disciplines. While a fully developed theory of CPSs requires more efforts and time, we propose this special session in AIAIM 2019 to present recent advances in communication-aware control and its applications in the design of practical CPSs.

II. Activities

Communication-aware control is currently a popular research topic, although it was studied under different setups by using different methods. This was witnessed by many special sessions in major control conferences. For example, they were organised at

- 20th IFAC, Toulouse, France, 2017;
- 56th CDC, Melbourne, Australia, 2017;
- 35th ACC, Seattle, USA, 2017;
- 10th Multi-Conference on Systems and Control, Buenos Aires, Argentina, 2016.

In each session, more than 40 people attended. The number of special sessions (or invited sessions) are growing and the contributors are also increasing. We thus expect a large number of contributors and attendees to our proposed special session as well.

III. Topics

In the proposed special session on "Communication-aware control in cyber-physical systems", we aim to shed light on the recent advances related to communication-aware control as well as reviews on seminal achievements in this field over the past years. The possible presentations are solicited for, but not limited to the following tracks:

- Sampled-data control and time-triggered control;
- Event-triggered and self-triggered control;
- Intermittent feedback control;
- Energy-constrained control;
- Resilient control.

All the submissions will be evaluated by peer review.

References

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[3] K. You, N. Xiao, and L. Xie, *Analysis and Design of Networked Control Systems*. Springer-Verlag London, 2015.

[4] P. Tabuada, "Event-triggered real-time scheduling of stabilizing control tasks," *IEEE Transactions on Automatic Control*, vol. 52, no. 9, pp. 1680–1685, Sept 2007.

[5] V. Varma and R. Postoyan, "Energy efficient time-triggered control over wireless sensor/actuator networks," in *55th IEEE Conference on Decision and Control*, Dec 2016, pp. 2727–2732.